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Determination of body density for twelve bird species

Each year, bird collisions with military and civil aircraft worldwide result in tens of millions of pounds sterling of damage and occasional pilot/passenger injuries or deaths (Becker 1988, Dekker & Buurma 1990, Jacoby & Severtzov 1990, Shergalin 1990, Thorpe 1990b). For example, Thorpe (1990a) noted 488 reports of bird-damaged engines for commercial aircraft from 12 European countries, 1981–1985. Since 1987, seven United States Air Force (USAF) personnel have died and 11 aircraft have been lost as a result of bird–aircraft collisions (D. Harrington, pers. comm.). Military and civilian organizations worldwide simulate bird–aircraft collisions to test the resistance of aircraft components (e.g. Manuel 1984, Neveux 1986, Shorr 1990, Devaux 1992). Present techniques and standards were established using incomplete biological data.

The Domestic Chicken *Gallus domesticus* is currently used in most bird–aircraft collision tests. How the density, length and diameter of chickens compare with those of other bird species most often involved in collisions with aircraft is unknown. How these possible differences affect interpretations of bird–aircraft collision tests is unclear also.

Previous studies have indicated a range of densities in wild birds. Allcock and Brough (1967) determined the mean density of seven bird species to be 0.98 g per cm^3. The mean density of 23 aquatic bird species, calculated from a buoyancy study, was 0.68 g per cm^3 (Lovvorn & Jones 1991). Welty and Baptista (1988) reported that the relative density of a "duck" was 0.9 g per cm^3 as compared with a density of approximately 1.0 for humans. Challita (1981) reported a density of 0.96 g per cm^3 as being "similar to the density of real birds and equal to the density of . . . substitute birds". Wilson *et al.* (1992) showed that the density of diving birds was greater than that of birds not reliant on diving for foraging.

Replacement of Domestic Chickens with more representative wild species or an "artificial bird" for bird–aircraft collision tests has been discussed for many years (Devaux 1992), but no agreement has been reached on the standards for acceptable substitutes. An understanding of avian body density is essential to (1) aid standardization of international bird–aircraft collision testing techniques, (2) establish the acceptability and validity of using various indicator species or "artificial" birds for bird–aircraft collision testing and (3) establish international design standards for aircraft components regarding bird–aircraft collision resistance. Such data should also be useful in ornithological studies related to flight energetics and other factors. Our objective was to determine densities for 12 bird species (six common in both Europe and North America and six primarily North American species) that are involved in bird–aircraft collisions. The relationships of density to body length, diameter and wingspan were also examined.

METHODS

Data were collected on 12 individuals of each of the following 12 species: Starling *Sturnus vulgaris*, House Sparrow *Passer domesticus*, Rock Dove *Columba livia*, Canada Goose *Branta canadensis*, Mallard *Anas platyrhynchos*, Herring Gull *Larus argentatus*, Laughing Gull *Larus atricilla*, Ring-billed Gull *Larus delawarensis*, Turkey Vulture *Cathartes aura*, Brown-headed Cowbird *Molothrus ater*, Common Grackle *Quiscalus quiscula* and Domestic Chicken. Most species tested were chosen due to their frequency of collisions worldwide with aircraft, their range in mass and the lack of body density information. We attempted to test six males and six females of each species; however, owing to limitations in pre-test sex identification and availability, these samples sizes were not achieved for six species.

Laughing Gulls were obtained from John F. Kennedy International Airport, New York (Dolbeer *et al.* 1993). Domestic Chickens were obtained from the USAF Bird Strike Testing Facility, Arnold Air Force Base, Tennessee. Birds of the other ten species were collected in northern Ohio. Most birds were measured within 1 h of death. When an individual could not be measured on the day of its death, the bird was frozen. To determine the effects of freezing on density, we killed and froze eight Brown-headed Cowbirds for 7–25 days and compared their density with that of 12 other Brown-headed Cowbirds tested immediately after death.

Densities were determined using water displacement, similar to the technique used for humans (Consolazio *et al.* 1963). Our devices consisted of PVC pipes 0.6–1.2 m tall and 7.6, 10.2, 15.2 or 25.4 cm in diameter. Each tube, fitted with a support base, had an overflow spout 7.6–28.0 cm down the side which directed displaced water into containers. Bird immersion cages made of welded wire were fitted for each tube.

Each tube was calibrated with known density samples of titanium on a day it was used. The tube was filled with water at room temperature (22.3 ± 2.4°C, mean ± s.d.) and to which one drop (0.02 ml) of detergent had been added per 2 l of water to reduce the surface tension of the water. Calibration was accomplished by placing the titanium into the tube for 5 min and collecting all displaced water in a pre-weighed catch basin. Mass of the displaced water was determined and then converted to cubic centimetres to determine density of the titanium sample. This process was repeated until we were within 5% of the known density of the titanium.

Birds ≤1 kg and >1 kg were weighed to the nearest 0.1 g and 1.0 g, respectively. For each bird, mass was recorded before dry, wet and plucked volumes were measured. All body measurements were taken to the nearest millimetre. Total length was measured from the tip of the bill to the tip of the longest rectrix when the bird was laid on its back, and enough force was used to stretch the neck to its full length. The length of the tail was measured from the tip of the longest rectrix to the point where it emerged from the skin. Body length was calculated by subtracting tail length from total length. Wingspan was measured from wing tip to wing tip while the bird was on its back with wings fully extended (Pettingill 1967). Circumference was measured around the mantle and chest, before and after the bird was plucked. Feather mass was determined by subtracting mass of plucked birds from that of dry, unplucked birds.

Dry bird volume was measured using the same procedure as for the verification tests with titanium. Each bird was placed in an immersion cage head first with wings pulled back to minimize trapped air. Each bird was left in the tube for 5 min to allow all displaced water to be collected. Canada Geese, Herring Gulls and Turkey Vultures had rubber bands placed around their bills to prevent water from entering the oesophagus.

To determine wet bird volume, each bird was then immersed in a container of water containing surfactant at the same concentration as the test water. Feathers were stroked from posterior to anterior to remove trapped air and to completely wet the feathers. The bird was removed from the water, weighed and then transferred to the immersion cage and into the tube where wet bird volume was measured using the same procedure as for the dry volume measurement.

After wet bird volume was obtained, all feathers were removed to determine plucked bird volume using the same procedure. Except for Domestic Chickens, three volume tests were completed for each bird: dry, wet and plucked. Only dry and plucked tests were done on chickens.

The sex of each bird was determined by gonadal examination. Density (g/cm^3) was calculated using the formula $D = m/V$, where D = body density, m = body mass and V = body volume.

Table 1. *Mean (±s.d.) initial mass (g), density (g/cm³) and length to diameter (L/D) ratio of 12 specimens of each of 12 species when they were dry, after soaked in water and after plucking all feathers. Species with statistically similar mean densities (within each column) share common uppercase letters (Tukey test,* P < *0.017)*

Species	Initial mass (g)	Density (g/cm³) Dry[a]	Wet[b]	Plucked[c]	L/D ratio
Domestic Chicken	1798 ± 0	0.918 ± 0.041 A		1.044 ± 0.011 AB	4.2 ± 0.2
Common Grackle	96 ± 15	0.809 ± 0.030 B	0.924 ± 0.023 A	1.004 ± 0.024 BC	4.3 ± 0.3
Starling	72 ± 5	0.776 ± 0.035 BC	0.947 ± 0.024 A	1.027 ± 0.020 ABC	4.6 ± 0.3
House Sparrow	23 ± 2	0.751 ± 0.042 CD	0.913 ± 0.035 AB	1.050 ± 0.032 A	4.6 ± 0.2
Brown-headed Cowbird	42 ± 6	0.750 ± 0.029 CD	0.915 ± 0.024 AB	1.042 ± 0.028 AB	4.0 ± 0.2
Mallard	1329 ± 151	0.739 ± 0.040 CD	0.877 ± 0.026 B	0.959 ± 0.016 ED	6.0 ± 0.3
Turkey Vulture	1857 ± 165	0.700 ± 0.018 DE	0.803 ± 0.024 CD	0.916 ± 0.025 EF	4.1 ± 0.2
Laughing Gull	322 ± 27	0.700 ± 0.043 DE	0.831 ± 0.027 C	0.935 ± 0.039 E	5.2 ± 0.2
Canada Goose	3976 ± 710	0.669 ± 0.041 EF	0.807 ± 0.023 CD	0.917 ± 0.023 EF	5.8 ± 0.5
Rock Dove	323 ± 46	0.648 ± 0.032 EFG	0.802 ± 0.020 CD	0.987 ± 0.022 DC	4.0 ± 0.2
Ring-billed Gull	426 ± 52	0.644 ± 0.031 FG	0.786 ± 0.028 D	0.928 ± 0.034 E	5.3 ± 0.2
Herring Gull	1044 ± 190	0.602 ± 0.053 G	0.743 ± 0.046 E	0.880 ± 0.055 F	5.1 ± 0.3

[a] Species differed ($F_{11,120}$ = 64.14, $P < 0.01$). Sexes within each species were not different ($F_{1,120}$ = 1.0, n.s.), nor was there a species and sex interaction ($F_{11,120}$ = 1.12, n.s.).
[b] Species differed ($F_{10,110}$) = 66.54, $P < 0.01$).
[c] Species differed ($F_{11,120}$ = 46.83, $P < 0.01$).

We used the General Linear Models procedure (SAS Institute, Inc. 1988) to determine differences in density and feather mass among species and between sexes within species. Because the use of two or more related response variables (i.e. three measurements of density) to address a single hypothesis increases the probability of committing a type I error, we used the Bonferroni inequality technique to ensure that the type I error rate was ≤0.05 (Beal & Khamis 1991). To maintain this probability level, 0.05 was divided by the number of response variables (three) tested, resulting in significant differences at $P \le 0.017$. If differences occurred, Tukey tests were used to determine which means differed. We used a t-test to examine differences ($P < 0.05$) between frozen and fresh-killed Brown-headed Cowbirds. Correlation analysis was done between total length, wingspan, dry circumference and dry density.

RESULTS

Mean dry densities ranged from 0.602 to 0.918 g per cm³ for the 12 species, whereas wet densities ranged from 0.743 to 0.947 g per cm³ and plucked densities from 0.880 to 1.050 g per cm³ (Table 1). Results were consistent within each species and for each measurement. Domestic Chickens were either the most dense or among the most dense of the species tested and were denser than wild birds of similar mass. The Starling and Common Grackle were among the three most dense wild species in all three measurements. Herring Gulls were either the least or among the three least dense species in each density measure. Sexes did not differ in the three measures of density. Densities of frozen and fresh-killed Brown-headed Cowbirds were similar (t_{18} = 0.67, n.s.). The mean length : diameter ratio of the 12 species was 4.8 (s.d., ± 0.3). For all species, dry density was significantly negatively correlated with wingspan ($r_{142} = -0.52$, $P < 0.001$), dry circumference ($r_{142} = -0.23$, $P < 0.006$) and body length ($r_{142} = -0.26$, $P < 0.001$).

The percentages of body mass represented by feathers differed ($F_{11,120}$ = 25.3, $P < 0.01$) among species but not by sex ($F_{1,11}$ = 0.07, n.s.) or by sex × species ($F_{11,1}$ = 1.47, n.s.; Fig. 1). Herring Gulls, Turkey Vultures and Laughing Gulls had 9–10% of their body mass composed of feathers, whereas feathers formed only 2–4% of the body mass of seven other species.

DISCUSSION

Bird density appears to reflect energetic relationships between cost of locomotion and foraging. The gulls and waterfowl measured are not reliant on diving for foraging. They also make long, continuous flights and were among the least dense of the species tested. Turkey Vultures, which frequently soar, also had a low density. Starlings, House Sparrows, Common Grackles and Brown-headed Cowbirds, among the densest species tested, do not depend upon these strategies for survival.

The percentage of body mass represented by feathers also seems related to locomotor habits as the three species (Herring Gull, Turkey Vulture and Laughing Gull) with the highest proportions of feather mass are notable for soaring, aquatic habits or both. Canada Geese and Mallard, however, did not differ from Starlings, House Sparrows, Brown-headed Cowbirds or Common Grackles in feather mass as a percentage of body mass. Canada Geese and Mallard were captured during the flightless period of their postbreeding moult, which reduced the total mass of feathers. However, Canada Goose and Mallard body masses were not less than published masses (Dunning 1993).

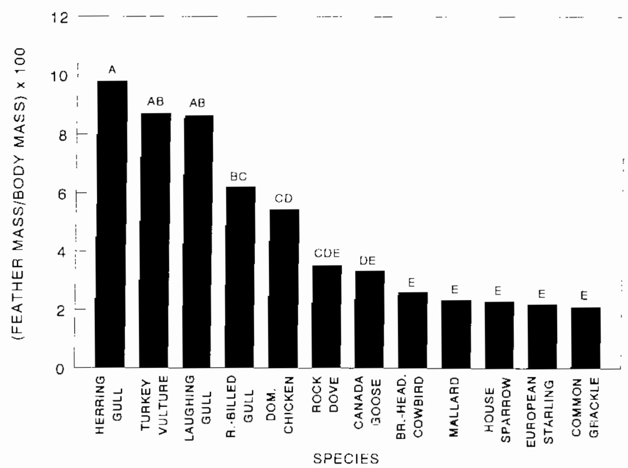

Figure 1. Feather mass represented as percentage of total body mass for 12 bird species. Bars that do not share a common letter are significantly different (Tukey test, $P < 0.05$).

Domestic Chickens are primarily terrestrial birds which have been bred for increased muscle mass and egg-laying capability (F. Muir, pers. comm.). Probably as a result, Domestic Chickens were more dense than most of the wild bird species tested. The use of Domestic Chickens for bird–aircraft collision tests therefore represents a worst case situation because of the species' high density. The Herring Gull and Mallard also have been used in bird–aircraft collision testing (T. Alge, pers. comm.) and were significantly less dense than Domestic Chickens. Since objects of different densities that strike an aircraft travelling at a consistent speed give different results (Babish, unpubl.), birds of different densities will give different results. Tests using less dense birds will not be as severe as those with denser birds and may produce inadequate design standards for engines or aircraft components.

The high density of the smaller birds (e.g. Starling, Brown-headed Cowbird) tested supports the theory of a "high speed–small bird" (feathered bullet) phenomenon (Urzi, unpubl.) whereby a single, small bird could cause damage to an aircraft travelling at high speed. Also, since species such as Starlings and Brown-headed Cowbirds generally travel in flocks, they may represent a serious threat to aircraft due to the combined density and mass of a flock as they strike an aircraft. For example, a Learjet crashed near Atlanta, Georgia, in 1973, killing eight people, after striking a flock of Brown-headed Cowbirds (U.S. National Transportation Safety Board 1973).

Engineers previously have used a 2:1 length : diameter ratio of artificial birds in aircraft–bird strike studies (Challita 1981). This ratio may be inappropriate because the smallest ratio we measured for 12 species was 4.0:1. A 4.8:1 ratio (the mean for the 12 species tested) would more accurately reflect the dimensions of birds that strike aircraft.

Further density studies on birds from various geographic regions are needed to determine appropriate species for use in bird strike tests, to enhance the development of "artificial" birds for bird strike tests and to develop a worldwide data base on bird densities for use in ornithological studies. Live bird densities may be lower than dead bird densities of the same species due to the volume of air in their lungs and air sacs. For the purpose of developing safer aircraft, data from dead birds, therefore, provide information for models that represent worst case situations. Correlation of carcass composition (protein, fat and ash) and whole body density also would help build a more complete model for the development of an artificial bird.

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